Introduction to Rice HPCToolkit on Early Access BlueGene/Q

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http://hpctoolkit.org

HPCToolkit Basic Features

- **Run application natively, every 100-1,000 times per second, interrupt program and record snapshot of call stack.**
- **Combine sampling data with binary analysis of program structure: loops, inline functions, etc.**
- **Present top-down, bottom-up and flat views of calling context tree (CCT) and time-sequence trace view. Costs are displayed per source line in the context of their call path.**
- **Can sample on Wallclock (itimer) and Hardware Performance Counter Events (PAPI preset and native events).**

Advantages of Sampling

- Run application natively at full optimization.
- Analyze program binary, no changes to source code.
- Low overhead, typically < 5%, overhead is proportional to sampling rate, not number of function calls.

HPCToolkit Advanced Features

- **Finely-tuned unwinder to handle multi-lingual, fully-optimized code, no frame pointers, broken return pointers, stack trolling, etc.**
- **Derived metrics -- compute flops per cycle, or flops per memory reads, etc. and attribute to lines in source code.**
- **Compute strong and weak scaling loss, for example:**

strong: 8 * (time at 8K cores) - (time at 1K cores)

weak: (time at 8K cores and 8x size) - (time at 1K cores)

- **Blame shifting -- when thread is idle or waiting on a lock, blame the working threads or holder of lock.**
- **Load imbalance -- display distribution and variance in metrics across cores and threads.**

Getting Started with HPCToolkit

- **Add to PATH:**

```
/home/projects/hpc/pkgs/hpctoolkit/bin
```

- **Compile source files natively with full optimization, add -g to CFLAGS (for source lines).**

- **Use hpclink to link application with hpctoolkit code.**

```
hpclink  mpicc  -o myprog  file.o ...  -llib ...
```

- **Launch program with HPCRUN environ variables.**

```
HPCRUN_EVENT_LIST=‘PAPI_TOT_CYC@15000000,
   PAPI_FP_OPS@1000000’
HPCRUN_TRACE=1    (for tracing)
qsub -A <project> -t <time> -n <nodes>  ...  \
    --env HPCRUN_EVENT_LIST=’...’:HPCRUN_TRACE=1  \
    myprog arg  ...
```

Getting Started, cont’d.

- Use hpcstruct to analyze program binary.

```
hpcstruct  myprog
=>  myprog.hpcstruct
```

- Use hpcprof or hpcprof-mpi to combine .hpcstruct file with measurements directory (use ‘+’ for subdirectories).

```
hpcprof  -S myprog.hpcstruct  \
   -I /path/to/myprog/source/tree/+  \
   hpctoolkit-myprog-measurements-jobid
==>  hpctoolkit-myprog-database-jobid
```

- Use hpcviewer and hpctraceview (if enabled tracing) to view results.

```
hpcviewer  hpctoolkit-myprog-database-jobid
hpctraceviewer  hpctoolkit-myprog-database-jobid
```

Where to find HPCToolkit

- Home page:

  http://hpctoolkit.org/

- On veas:

  /home/projects/hpc/pkgs/hpctoolkit/bin

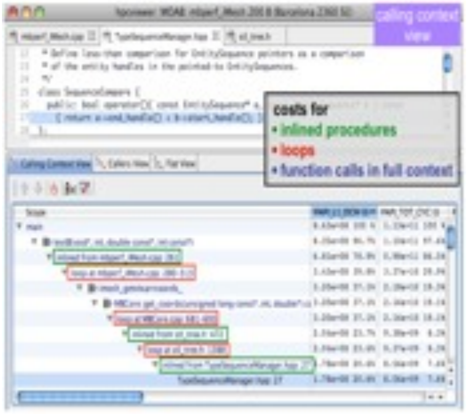
- Source code available for anonymous svn checkout at the SciDAC Outreach Center (hpctoolkit project).

  https://outreach.scidac.gov/projects/hpctoolkit/

- Prebuilt versions of the viewer and traceviewer also available at the SciDAC Outreach Center (hpcviewer project).

  https://outreach.scidac.gov/projects/hpcviewer/

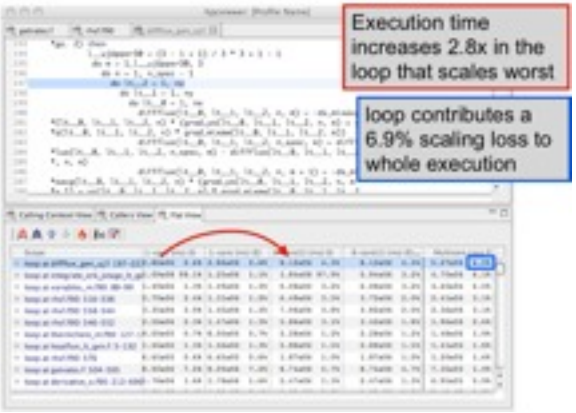
HPCToolkit Capabilities at a Glance



calling context view

costs for
- inlined procedures
- loops
- function calls in full context

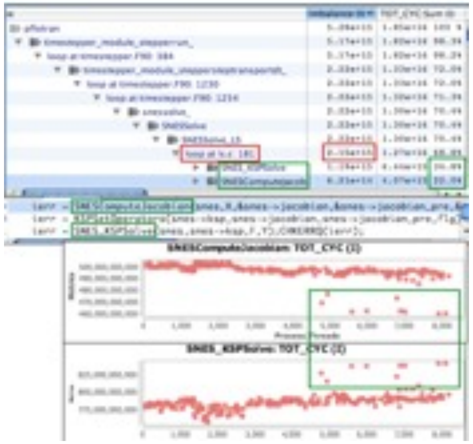
Attribute Costs to Code



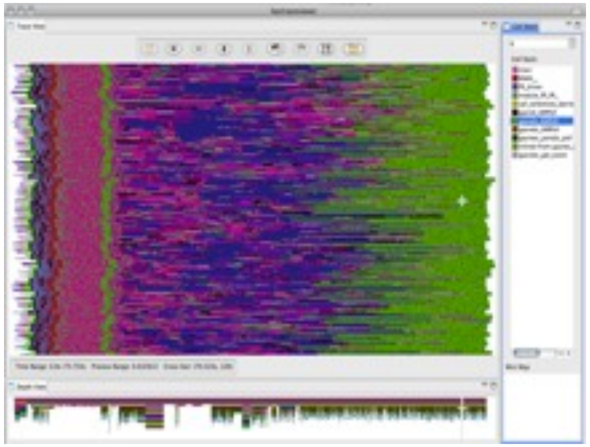
Execution time increases 2.8x in the loop that scales worst

loop contributes a 6.9% scaling loss to whole execution

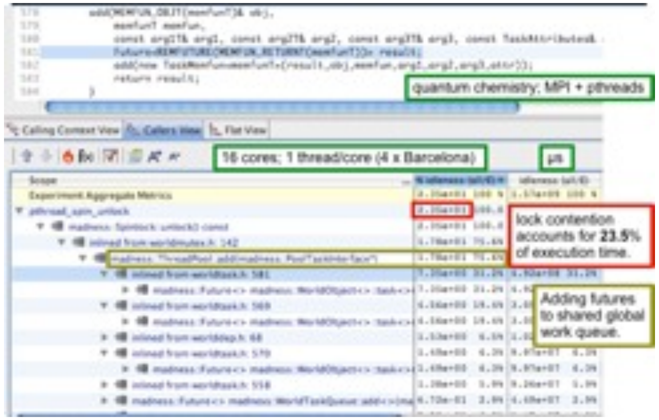
Pinpoint & Quantify Scaling Bottlenecks



Assess Imbalance and Variability



Analyze Behavior over Time



quantum chemistry; MPI + pthreads

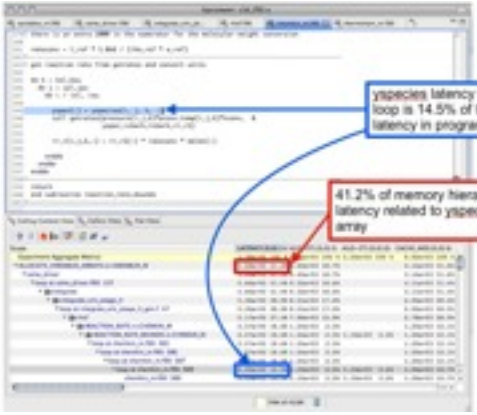
16 cores; 1 thread/core (4 x Barcelona)

μs

lock contention accounts for 23.5% of execution time.

Adding futures to shared global work queue.

Shift Blame from Symptoms to Causes



yspecies latency for this loop is 14.5% of total latency in program

41.2% of memory hierarchy latency related to yspecies array

Associate Costs with Data

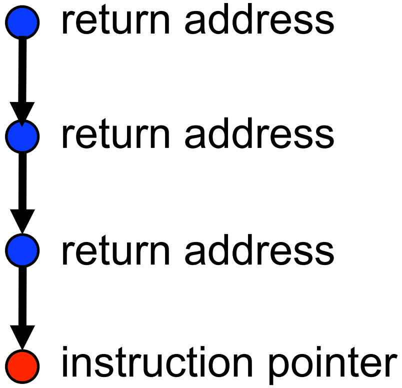
hpctoolkit.org

Call Path Profiling

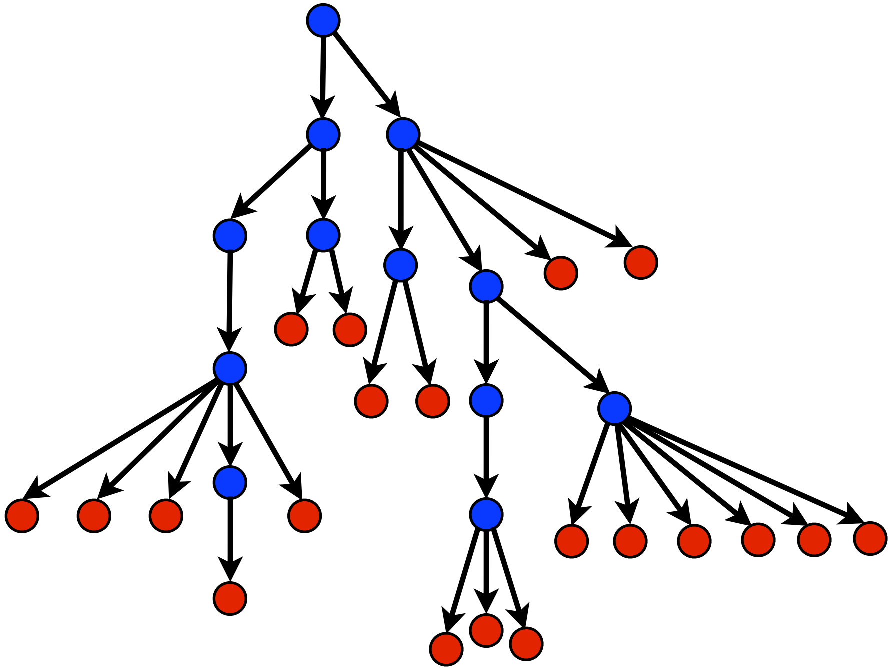
Measure and attribute costs in context

- **sample timer or hardware counter overflows**
- **gather calling context using stack unwinding**

Call path sample



Calling context tree

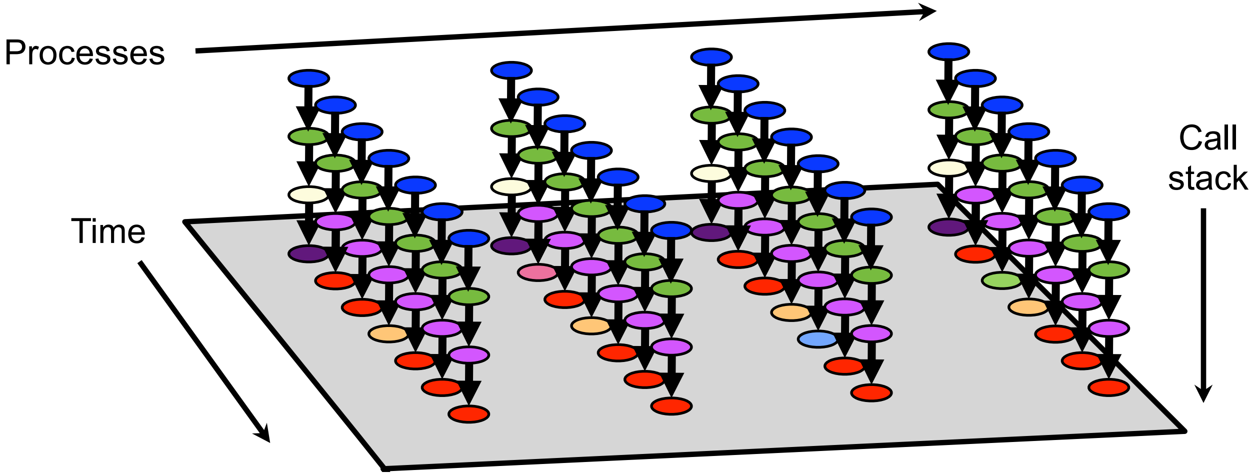


Overhead proportional to sampling frequency...
...not call frequency

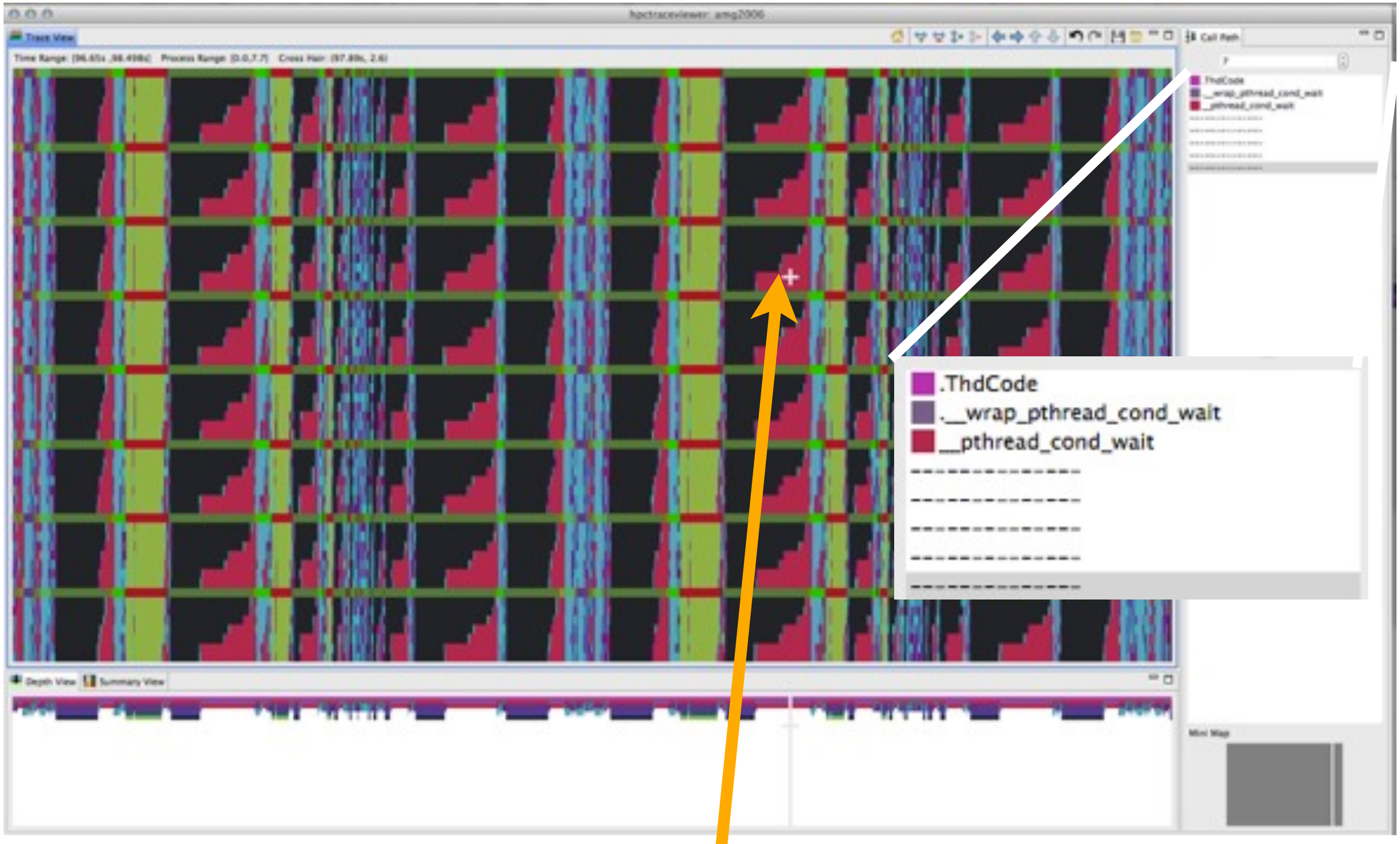
Understanding Temporal Behavior

- **Profiling compresses out the temporal dimension**
  - **—temporal patterns, e.g. serialization, are invisible in profiles**
- **What can we do? Trace call path samples**
  - **—sketch:**
    - **N times per second, take a call path sample of each thread**
    - **organize the samples for each thread along a time line**
    - **view how the execution evolves left to right**
    - **what do we view?**

assign each procedure a color; view a depth slice of an execution



AMG2006: 8PE x 8 OMP Threads

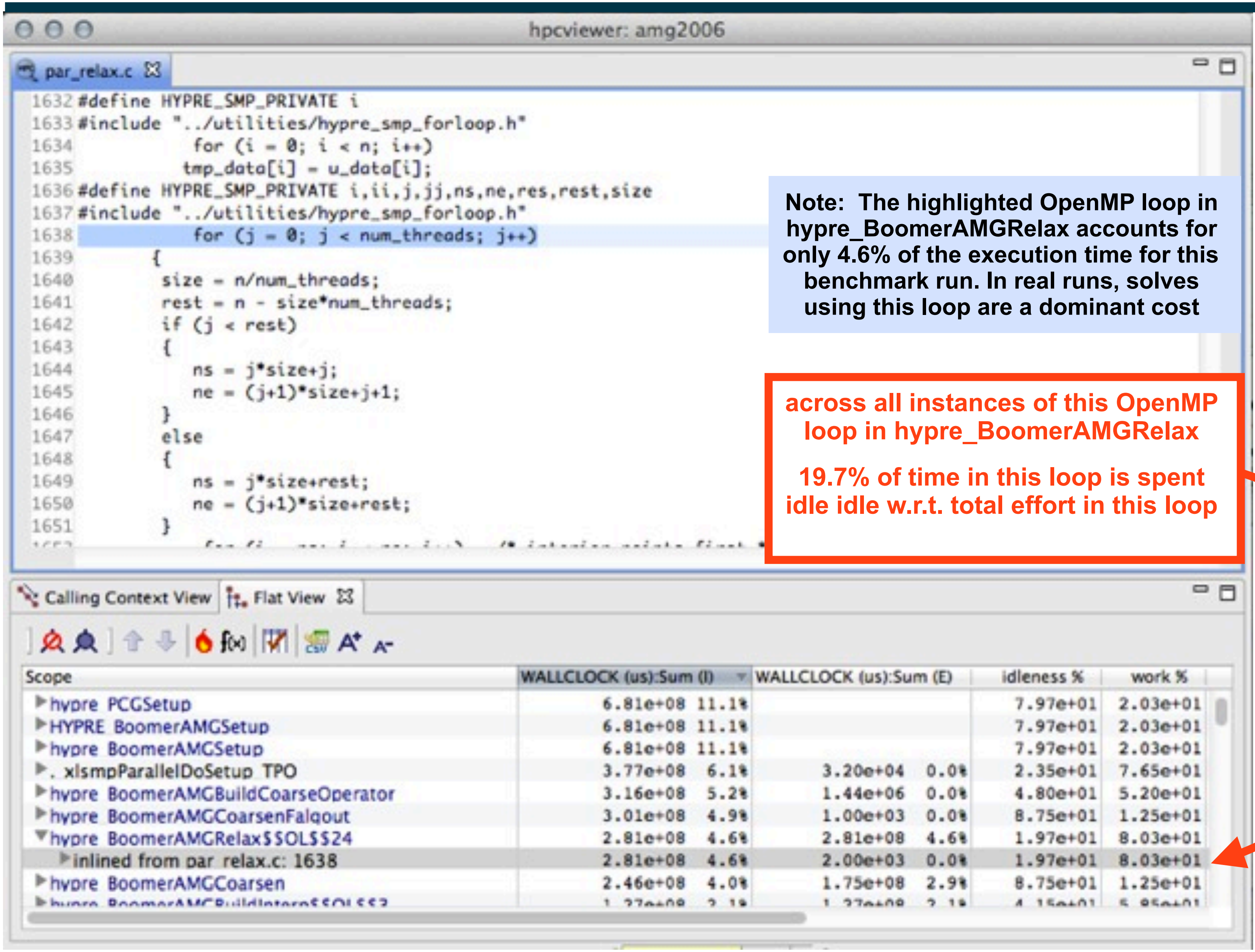


Time Range: [96.65s ,98.498s]   Process Range: [0.0,7.7]   Cross Hair: [97.80s, 2.6]

🟪 .ThdCode
🟪 .__wrap_pthread_cond_wait
🟥 __pthread_cond_wait

OpenMP loop in `hypre_BoomerAMGRelax` using static scheduling has load imbalance; threads idle for a significant fraction of their time

Code-centric view: `hypre_BoomerAMGRelax`



```
1632 #define HYPRE_SMP_PRIVATE i
1633 #include "../utilities/hypre_smp_forloop.h"
1634            for (i = 0; i < n; i++)
1635           tmp_data[i] = u_data[i];
1636 #define HYPRE_SMP_PRIVATE i,ii,j,jj,ns,ne,res,rest,size
1637 #include "../utilities/hypre_smp_forloop.h"
1638            for (j = 0; j < num_threads; j++)
1639         {
1640          size = n/num_threads;
1641          rest = n - size*num_threads;
1642          if (j < rest)
1643          {
1644             ns = j*size+j;
1645             ne = (j+1)*size+j+1;
1646          }
1647          else
1648          {
1649             ns = j*size+rest;
1650             ne = (j+1)*size+rest;
1651          }
1652             for (i = ns; i < ne; i++)   /* interior points first *
```

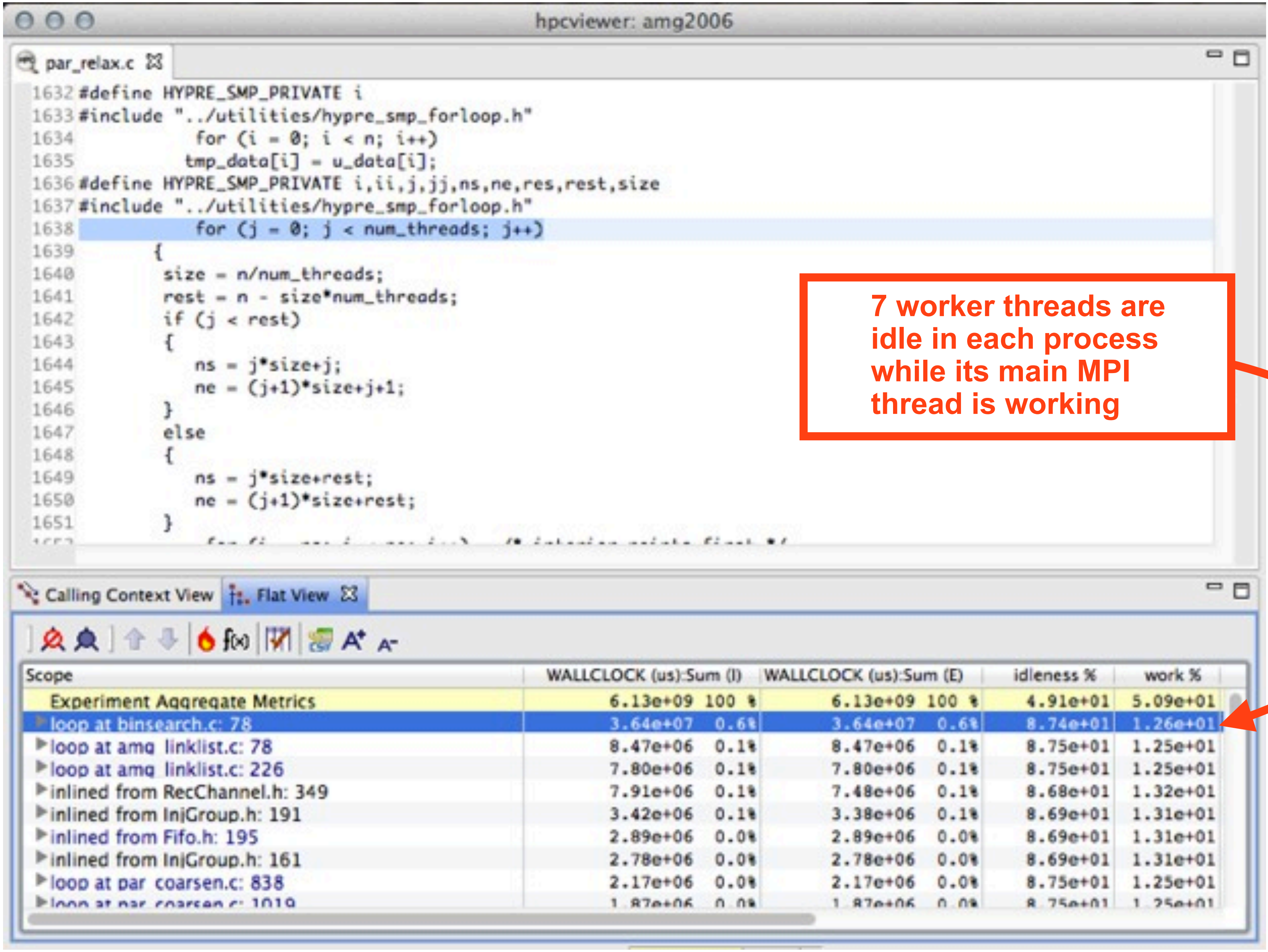
Scope	WALLCLOCK (us):Sum (I)		WALLCLOCK (us):Sum (E)		idleness %	work %
▶hypre PCGSetup	6.81e+08	11.1%			7.97e+01	2.03e+01
▶HYPRE BoomerAMGSetup	6.81e+08	11.1%			7.97e+01	2.03e+01
▶hypre BoomerAMGSetup	6.81e+08	11.1%			7.97e+01	2.03e+01
▶. xlsmpParallelDoSetup TPO	3.77e+08	6.1%	3.20e+04	0.0%	2.35e+01	7.65e+01
▶hypre BoomerAMGBuildCoarseOperator	3.16e+08	5.2%	1.44e+06	0.0%	4.80e+01	5.20e+01
▶hypre BoomerAMGCoarsenFalgout	3.01e+08	4.9%	1.00e+03	0.0%	8.75e+01	1.25e+01
▼hypre BoomerAMGRelax$$OL$$24	2.81e+08	4.6%	2.81e+08	4.6%	1.97e+01	8.03e+01
▶inlined from par relax.c: 1638	2.81e+08	4.6%	2.00e+03	0.0%	1.97e+01	8.03e+01
▶hypre BoomerAMGCoarsen	2.46e+08	4.0%	1.75e+08	2.9%	8.75e+01	1.25e+01
▶hypre BoomerAMGBuildInterp$$OL$$3	1.27e+08	2.1%	1.27e+08	2.1%	4.15e+01	5.85e+01

Note: The highlighted OpenMP loop in hypre_BoomerAMGRelax accounts for only 4.6% of the execution time for this benchmark run. In real runs, solves using this loop are a dominant cost

across all instances of this OpenMP loop in hypre_BoomerAMGRelax

19.7% of time in this loop is spent idle idle w.r.t. total effort in this loop

Serial Code in AMG2006 8 PE, 8 Threads

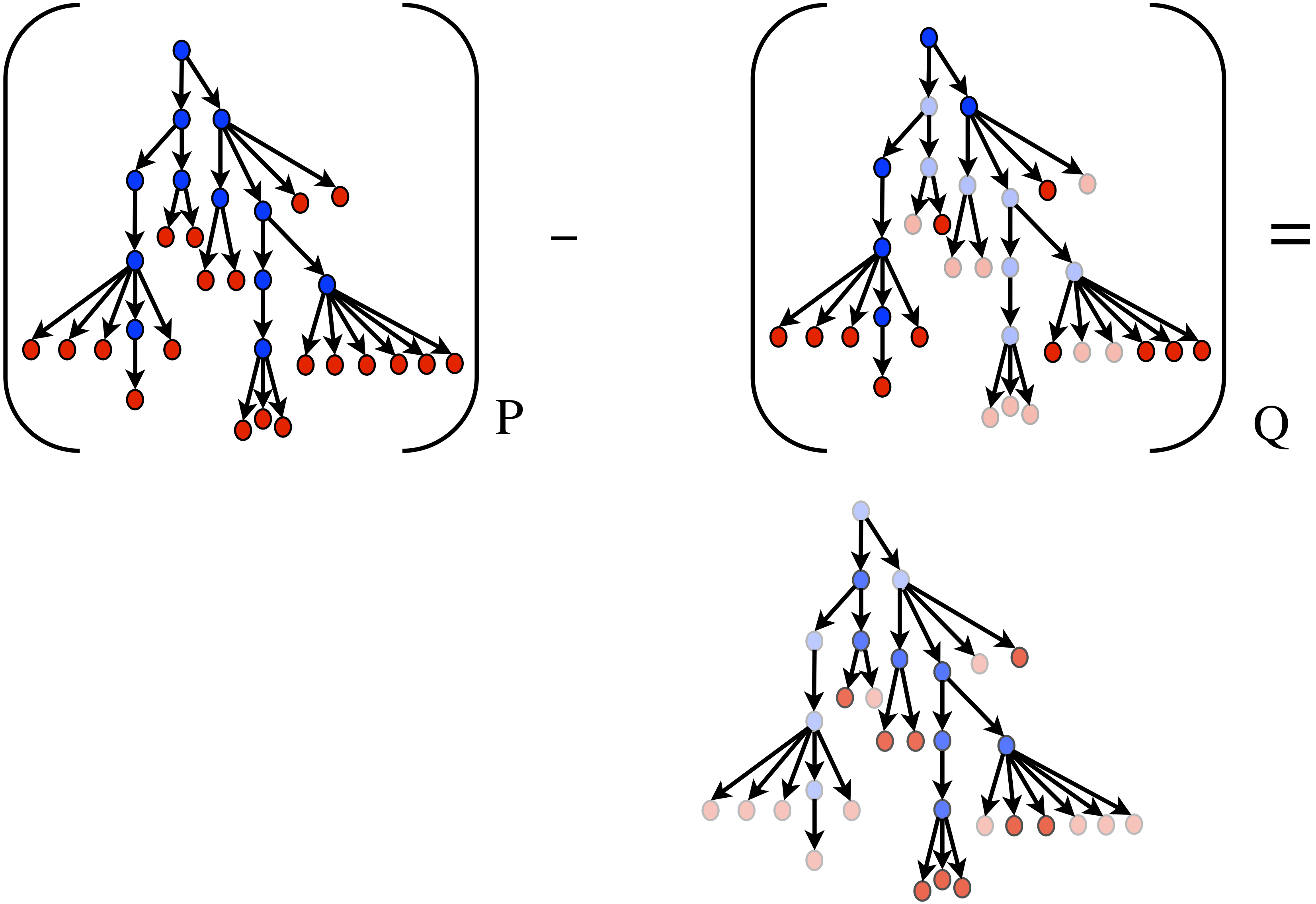


```
#define HYPRE_SMP_PRIVATE i
#include "../utilities/hypre_smp_forloop.h"
            for (i = 0; i < n; i++)
           tmp_data[i] = u_data[i];
#define HYPRE_SMP_PRIVATE i,ii,j,jj,ns,ne,res,rest,size
#include "../utilities/hypre_smp_forloop.h"
            for (j = 0; j < num_threads; j++)
        {
           size = n/num_threads;
           rest = n - size*num_threads;
           if (j < rest)
           {
              ns = j*size+j;
              ne = (j+1)*size+j+1;
           }
           else
           {
              ns = j*size+rest;
              ne = (j+1)*size+rest;
           }
              for (i = ns; i < ne; i++)   /* interior points first */
```

Scope	WALLCLOCK (us):Sum (I)	WALLCLOCK (us):Sum (E)	idleness %	work %
Experiment Aggregate Metrics	6.13e+09 100 %	6.13e+09 100 %	4.91e+01	5.09e+01
loop at binsearch.c: 78	3.64e+07 0.6%	3.64e+07 0.6%	8.74e+01	1.26e+01
loop at amg_linklist.c: 78	8.47e+06 0.1%	8.47e+06 0.1%	8.75e+01	1.25e+01
loop at amg_linklist.c: 226	7.80e+06 0.1%	7.80e+06 0.1%	8.75e+01	1.25e+01
inlined from RecChannel.h: 349	7.91e+06 0.1%	7.48e+06 0.1%	8.68e+01	1.32e+01
inlined from InjGroup.h: 191	3.42e+06 0.1%	3.38e+06 0.1%	8.69e+01	1.31e+01
inlined from Fifo.h: 195	2.89e+06 0.0%	2.89e+06 0.0%	8.69e+01	1.31e+01
inlined from InjGroup.h: 161	2.78e+06 0.0%	2.78e+06 0.0%	8.69e+01	1.31e+01
loop at par_coarsen.c: 838	2.17e+06 0.0%	2.17e+06 0.0%	8.75e+01	1.25e+01
loop at par_coarsen.c: 1019	1.87e+06 0.0%	1.87e+06 0.0%	8.75e+01	1.25e+01

7 worker threads are idle in each process while its main MPI thread is working

Pinpointing and Quantifying Scalability Bottlenecks



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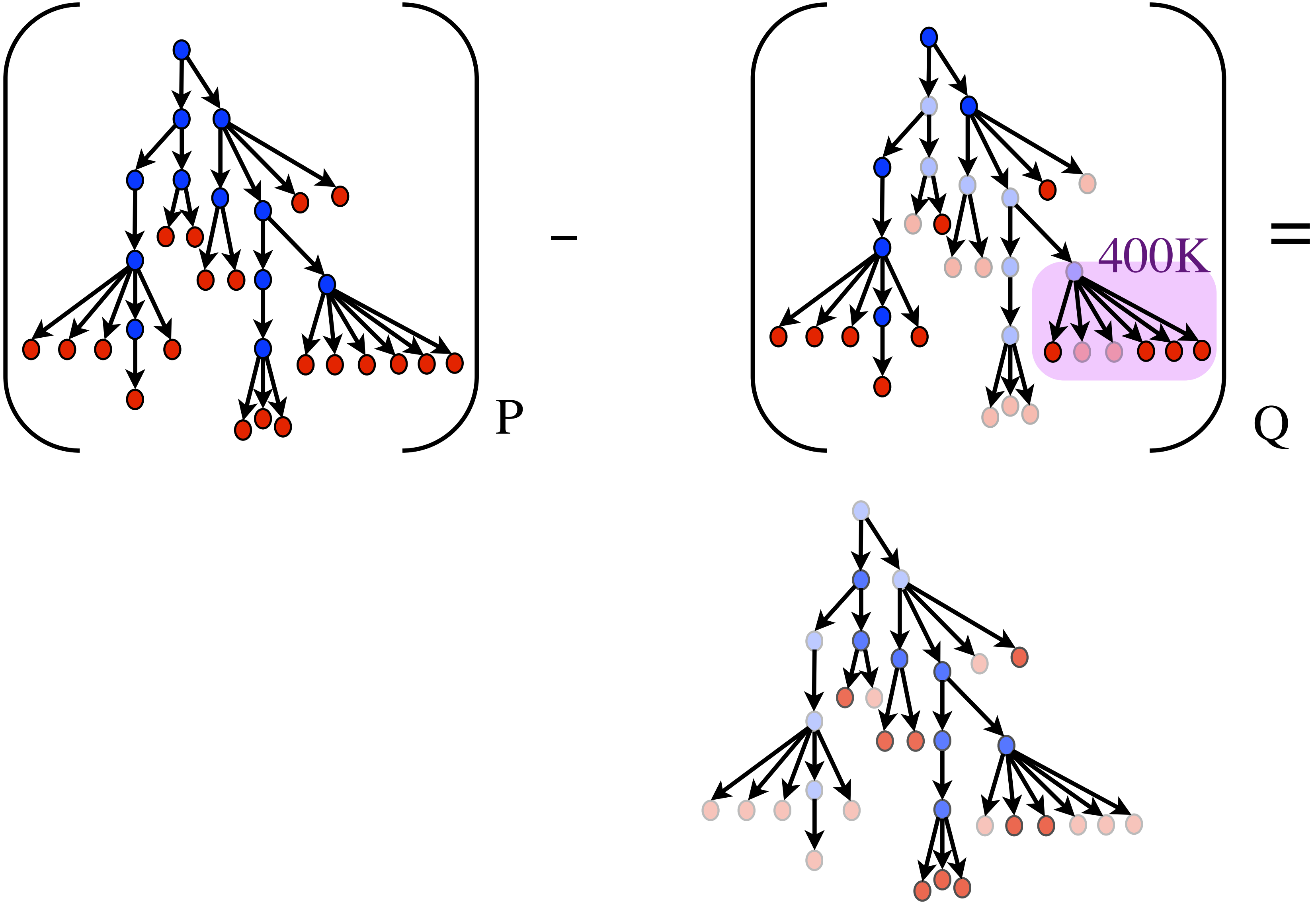

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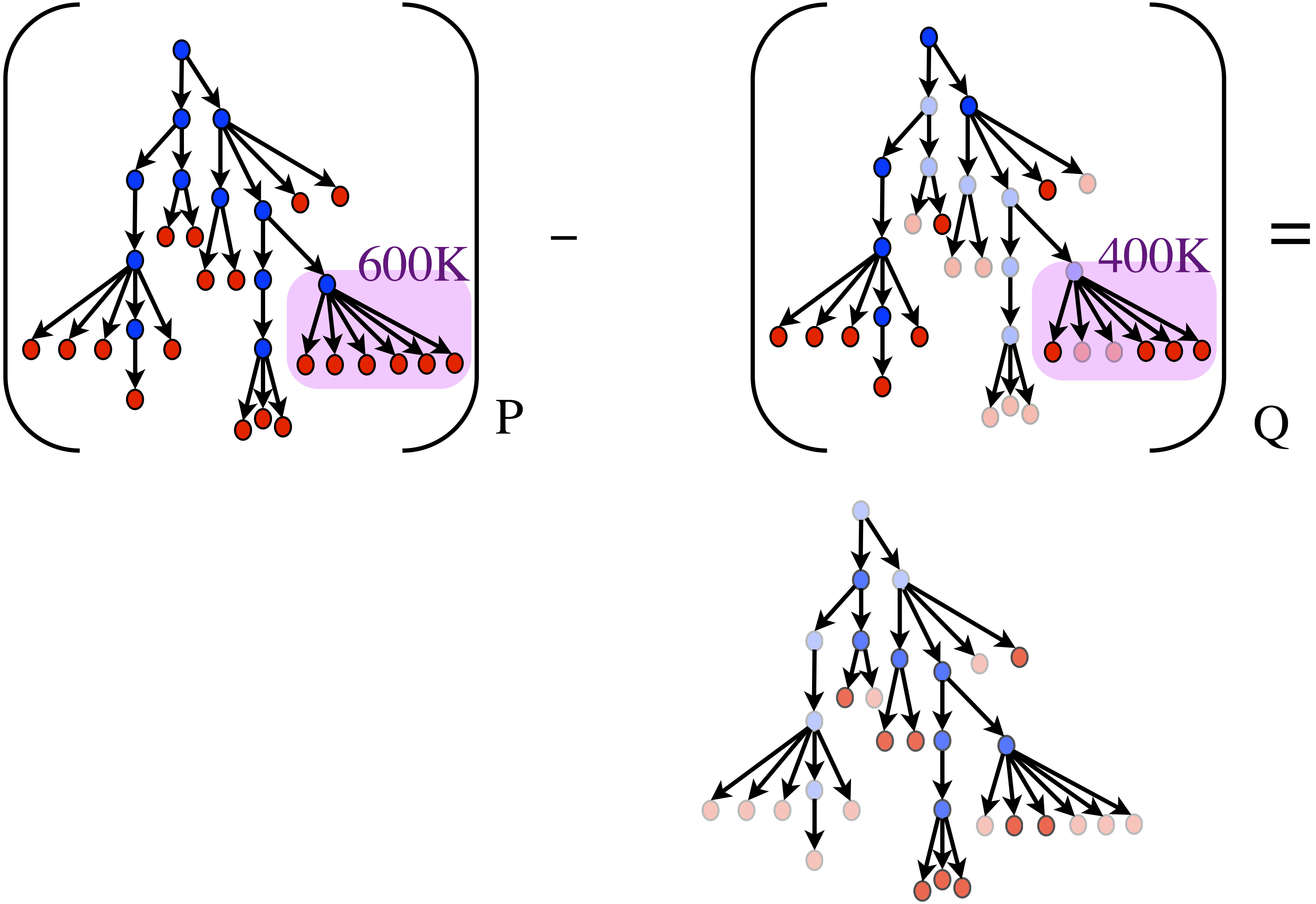

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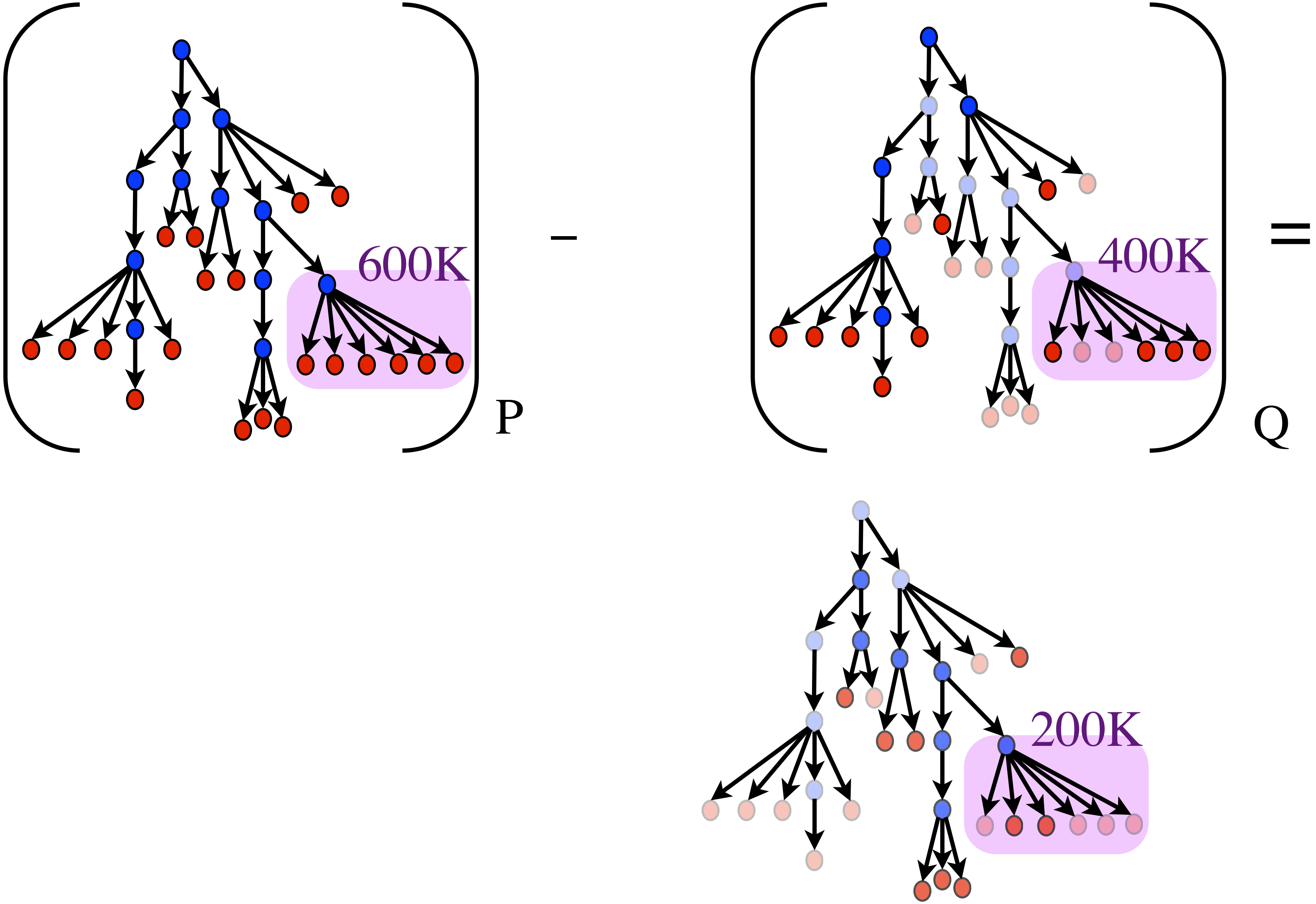
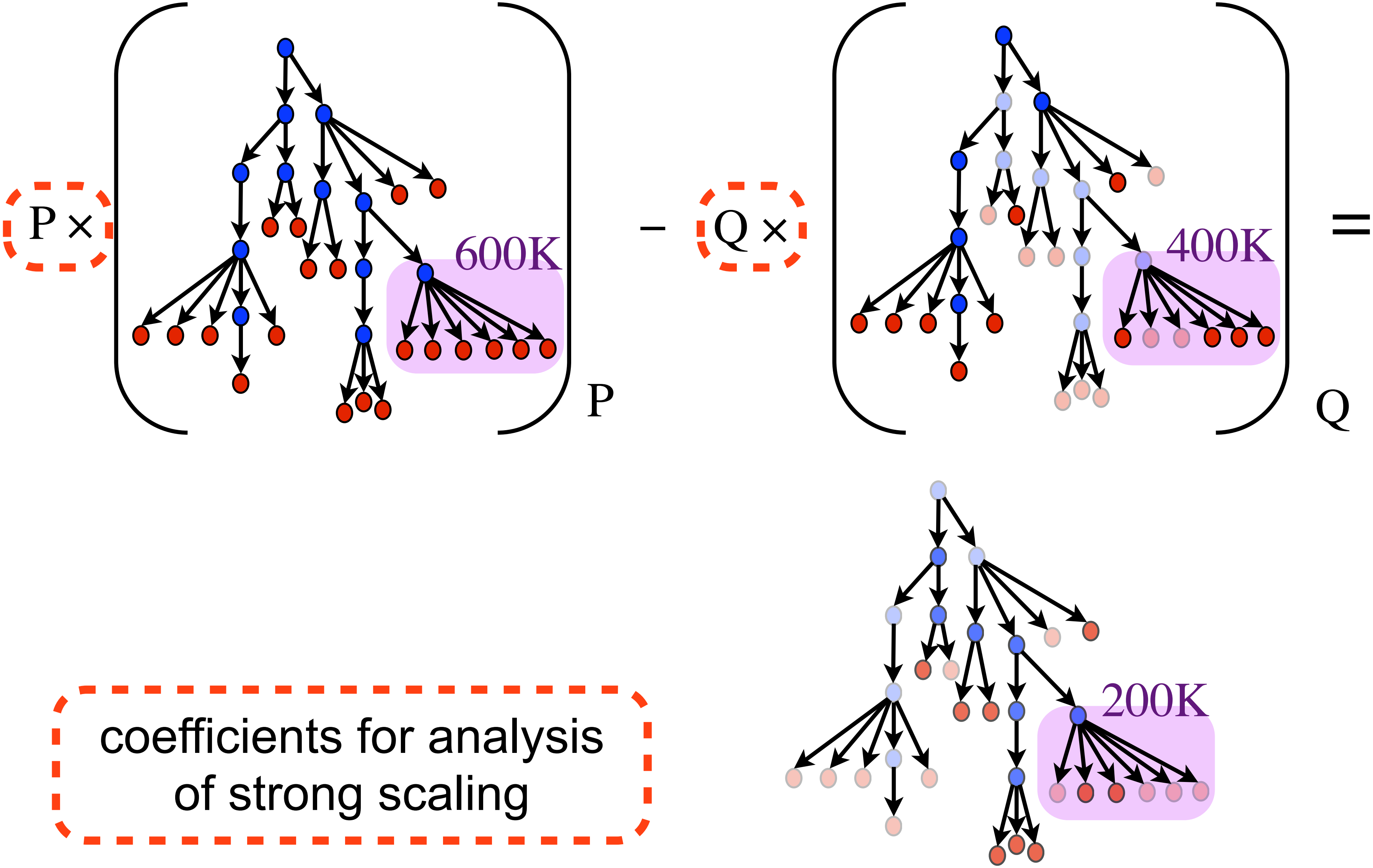


Pinpointing and Quantifying Scalability Bottlenecks



coefficients for analysis of strong scaling